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Research Article

Experimental study on a novel waterless solar collector

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ABSTRACT

This study is an endeavour to introduce a novel approach to enhance the performance of solar collectors. The sun emits sufficient power of solar radiation to meet the demand of energy. Harvesting the renewable solar energy needs advanced technologies and requirements. Solar ponds including salinity gradient solar ponds (SGSPs) are common solar collectors. These ponds are one of the solar energy applications used for many industrial and domestic purposes. However, challenges of the conventional SGSPs such as evaporation, salt diffusion, temperature discrepancy, and layer mixing profoundly and significantly affected their expansion globally. A novel experimental solar collector configuration to overcome the challenges of the conventional solar ponds (solar collectors) is investigated, there is no water body and no salinity gradient to build; it is entirely a collector with no water body. The experimental unit was constructed in an arid area. It is basically a cylindrical tank with a total depth of 1.4 m with three zones or layers to store heat namely, paraffin wax layer (10 cm thickness). The paraffin layer was covered with a layer of coal with a thickness of 30 cm. On the top of coal layer, an air gap with a thickness of 80 cm was left. A clear plastic cover with a thickness of 0.2 cm was utilized to cover the constructed layers and making the air gap. The experimental unit was monitored, and temperature measurements were collected for the period of 17/7/2021-30/9/2021. The results demonstrated that temperature of the paraffin wax layer reached more than 48 °C in a short period and with a small day and night discrepancy (1 °C). Temperature of the paraffin layer remained constant around 43 °C even in night-time during the period of the study. Furthermore, the results showed that temperatures of coal layer and air gap reached the maximum at the daytime of 53 °C and 71 °C respectively with a clear discrepancy between day and night. The results of the present study are encouraging for more investigations in this new direction of solar collectors.

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INTRODUCTION

In last years, energy demand is getting rapid and global attention, especially clean energy. Clean energy, sometimes referred as renewable energy, has become popular and widely used in developed countries. The reason is that, clean energy uses multiple sources releasing no harm effect to the environment. This fact encourages researchers in renewable energy field to investigate innovative ideas to produce and store energy; this is because renewable and sustainable energies can produce energy with low or no risky consequences on ecology. In other words, they are clean sustainable and environmentally friendly energy resources. Previously, it has been recommended to focus on developing high performance, affordable, and low maintained sustainable and renewable thermal energy storages [1-3].

Solar collectors are devices or systems that collect or sometimes concentrate the incident solar radiation. They have the potential to supply thermal energy for a wide-range of applications in domestic and industry. The utilisation of solar collectors could be potentially the suitable and promising alternative of conventional thermal energy suppliers. Solar collectors and in particular solar ponds are thermal storages with high capacities. Its time is back to the sixties of last century (1960) [4]. The prior efforts in this field concentrated on the generation of electricity by the utility of solar ponds to supply thermal heat to generate the required vapour [5]. Generally, solar ponds can be divided into two types: convecting and non-convecting solar ponds. Non-convecting solar ponds are the most common and applicable type. While this type includes gel ponds, membrane ponds, the most common type of non-convecting solar ponds is the salinity gradient solar pond (SGSP) which is the focus of current study [4].

Salinity gradient solar pond is a body of water represented by three main zones: the upper convective zone (UCZ), the non-convective zone (NCZ) and the lower convective zone (LCZ). Convective currents occur in both the UCZ and the LCZ whereas there is no convection in the NCZ [6-10]. When the water body of a SGSP is constructed, the upward convection heat transfer from the LCZ will be suppressed by the presence of the NCZ. This is achieved by the availability of the salinity gradient in the zone (NCZ), and consequently this layer works as a transparent thermal insulator [11-13]. Thermal heat mostly extracted from the storage zone (LCZ), meanwhile there were some trials to extract heat from both the NCZ and LCZ. It was concluded that heat extraction from the two zones (NCZ and LCZ) increased thermal efficiency of the investigated SGSP [14-16]. Although SGSPs are simple and cost-effective manners to collect and store thermal energy, there are some challenges diminish their use and subsequently their extension around the world [17-18].

On the top of these challenges is the salt diffusion which affects the stability of the SGSP in general and the NCZ of the pond in particular. In recent years, a great effort has been made in optimizing the overall performance of solar ponds technology [19-20]. It was claimed that in SGSPs, the NCZ that acts as a thermal and mass insulator for the LCZ requires careful monitoring and maintenance to prevent or diminish convection heat transfer and to maintain its stability. With the time progress, temperature of the LCZ increases and consequently there is an increase in temperatures of the lower layers of the NCZ close to the LCZ. This increase in the temperature will lead to a convective movement at the bottom of the NCZ which causes a heat and mass transfer. Therefore, the NCZ of the pond could be transferred gradually to be a well-mixed zone. Additionally, wind speed noticeably affects the water body of a SGSP by accelerating layers mixing of the pond. It also increases evaporation rates from the surface of the pond [21]. This discussion leads to evidence that it might be the most significant hindrance to the performance of the SGSPs is the salt diffusion upwardly from the LCZ to the UCZ throughout the NCZ. The diffused salt will be accumulated and finally concentrated in the UCZ. This issue requires a continuous treatment or maintenance, and this is performed by the continuous salt injection to the LCZ with continuous surface wash to the UCZ. This process makes the SGSP a costly application.

Furthermore, Evaporation has been shown previously to be the major mode of heat loss from the surface of the UCZ of the SGSP comparing to convection and radiation heat loss mechanisms. This indicates that this layer (UCZ) needs to be maintained by the addition of fresh water to substitute the evaporated water. It was also observed that when surface evaporation was suppressed or eliminated, there was a significant increase in the temperatures of both the LCZ and UCZ [22]. In the arid areas including the area of the present study, evaporation levels are high and particularly in the hot season (summer). For example, Sayer et al., 2017 [21] found that in Nasiriya City (area of the present study), evaporation levels varied from 5.35 L/m^2 day in March to reach the highest in June 17.68 L/m^2 day. These values are undoubtedly effective and would profoundly and considerably increase the cost of the pond, in addition to the heat loss. They introduced an example that the construction of a large SGSP with a surface area of 1000 m^2 in the city of Nasiriya in Iraq (arid area) requires about 17000 litres daily to compensate the evaporated water from the surface of the pond in the hottest months of June, July, and August (summer season). Furthermore, it was claimed that in arid areas, when a SGSP is used to supply heat to a desalination process, the quantity of water required to compensate the evaporated water from the surface of the pond was more than the produced desalinated water, and this would negate the purpose for the desalination process [23]. It can be said clearly that evaporation adds another barrier to prevent or diminish the expansion of SGSPs. The complete removal of evaporation problem would tremendously decrease difficulties of constructing SGSPs and extend their applications globally. Ruskowitz et al. [23] experimentally investigated the performance of a SGSP when evaporation is decreased. They concluded that there was a noticeable increase in the temperature of the LCZ and UCZ of the pond. Sayer et al. [21] conducted that relative humidity has a significant influence on evaporation from the surface of solar ponds and consequently on the performance of these ponds. This influence varies seasonally; in the arid and dry areas, the highest effect on the performance of the SGSP was observed in summer season. On the other hand, the effect of relative humidity decreased in winter season [21].

Another challenge affects the temperature increase and consequently the performance of the SGSPs which is the temperature variation between day and night. It was previously observed that temperature of the LCZ varies between day and night by about 5-6 °C and might be more particularly in winter season. In the night the temperature of the LCZ decreases and it increases again in the daytime when the pond receives further insolation [24]. This behaviour prolongs the time of warming up of SGSPs.

Moreover, SGSPs have a negative influence on the environment due to the use of huge amount of salt to build up the saline water body of the pond. Salts come from the continuous wash to the UCZ or leaks in the base or walls of the pond will accumulate and pollute areas around the pond.

Finally, rain and high wind speed would increase the layer mixing of a SGSP. This will negatively affect the salt concentration of all zones of the pond and consequently its performance.

The discussed challenges significantly affect the interest in SGSPs and therefore the expansion of this technology globally. To this end, the present study is an attempt to overcome these obstacles by investigating a new and novel design of a solar pond. The innovative design eliminates all aforementioned drawbacks that already faced the practical applications of the SGSPs by avoiding the use of water and salt in the solar ponds by the utility of a phase change material (PCM). Paraffin wax (PCM) was used as an alternative material to the storage zone (LCZ). In the novel design, the decrease in the temperature between day and night was tackled by using coal and air gap as heat absorbers and insulators. It is the first trial to build a solar pond with no water body which means no salt diffusion, no layer mixing, no water addition to compensate the UCZ and no soil salt pollution. Moreover, this study is the first attempt to eliminate the complexity associated with the implementation of conventional SGSP by eliminating the three water zones representing water body of the pond. It is significant and beneficial to change the direction of solar ponds to be more practical and applicable. The present novel approach could open the door for extensive research to enhance the performance of solar ponds and subsequently extend their industrial applications. These applications require low-grade heat to work. The novel experimental pond consists of many layers including the PCM's layer (paraffin wax), coal layer and a gap (air layer) on the top of the coal layer. The pond can be covered with a clear glass or plastic cover. To decrease convection heat transfer from the surface, a thin gel layer can be used.

Paraffin wax is a white, odourless solid material with a typical melting point range between approximately 46 and 68 °C having a density of approximately 0.9 g/cm^3. Paraffin wax is a safe material and has low thermal conductivity (0.25 W/m. K), with a high heat capacity. This material is insoluble in water.

Cellulose, the most abundant organic material in nature, is entirely insoluble in water. To increase the solubility, the carboxymethyl group is added to the compound (cellulose) to produce a new compound which is carboxymethyl cellulose (CMC). CMC is a gel material, soluble in water forming a clear solution. This gel has no harmful influence on the environment and consequently could be used to form a thin gel layer above the cover of the suggested pond.

EXPERIMENTAL WORK AND MATERIALS

Construction of the Experimental Pond

The experimental pond was constructed at the Department of Chemistry-College of Science, University of Thi-Qar in Nasiriya City, south of Iraq. An entire description to all civil engineering works to the solar collector was implied by Sayer et al., 2022 [24]. The experimental unit had a cylindrical geometrical shape with a total depth of 1.4 m and a diameter of 1.4 m. Walls of the constructed pond were built from brick with a wall thickness of 20 cm. Then, the experimental unit was skimmed internally and externally with a layer of concrete to leak-proof; this layer had a thickness of 2 cm. For efficient thermal insulation, the experimental unit was surrounded by a 10 cm layer of insulating materials. The thermal insulator comprises two layers: the first layer was a 5 cm layer of glass wool with a thermal conductivity of K=0.04 W/m. K. The second layer of the insulator was a 5 cm layer of polystyrene with a thermal conductivity of K= 0.03 W/m. K. For efficient thermal insulation and to close holes, sawdust with K=0.08 W/m. K [25] was added.

In the novel approach of the solar collector investigated in the present study, there is no salinity gradient to be built and no water body to be maintained or layers to be established. The novel solar collector is entirely different from the conventional solar collectors. To construct the solar collector, a layer of paraffin wax with a thickness of 10 cm was inserted and fixed in the bottom of the experimental unit. The used paraffin wax in the present study had a white colour, a density of 0.8 g/cm^3, and a melting point range of 40-65 °C. To form the used paraffin wax layer, 122 kg of paraffin wax were used. Paraffin wax is a phase change material, when it is in solid state, it can absorb and store thermal heat of the incident solar radiation throughout the day-time converting to the liquid phase when the temperature reaches the melting point. Then it supplies heat when it is required and returns to the solid state when heat is extracted. In this layer, a copper coil with 0.375-inch internal diameter and 12 m long was fixed for the heat extraction purposes.

On the top of paraffin layer, a layer of local coal was added to represent 30 cm thickness of the coal layer. This layer has the ability to absorb the incident solar radiation and prevent or decrease heat loss from paraffin wax due its low thermal conductivity (0.2 W/m. K). The two layers (paraffin wax and coal) had a total depth of 40 cm.

A gap of air with a depth of 80 cm was left above the coal layer, and this was to decrease convection heat loss upwardly from the bottom layers of the collector. The gap was made by covering the pond with a glass cover with a thickness of 0.4 cm. To fix the glass cover, an iron frame was used to carry this cover. Figure 1 shows photographs of the experimental solar collector.

To diminish heat loss from the surface of the glass cover, a gel layer of CMC was added with a thickness of 5 cm on the top of the glass cover. The CMC gel layer had a concentration of 1%. The solution of CMC was prepared by dissolving 0.75 kg of CMC in 76 litres of water (the required water to form a layer of 5 cm thickness). The function of CMC is to decrease heat loss from the top of the solar collector by the mechanism of convection. Unfortunately, after two days of experiments, the glass cover was broken and that might be due to the temperature difference between the internal and external surfaces of the glass cover. To overcome the occurred difficulty, the glass cover was replaced with a clear PVC cover with a thickness of 0.2 cm. The total depth of paraffin, coal, and air gap layers became 120 cm. The rest depth of the constructed pond was left empty to protect the upper layer from dust and wind effects. Figure 2 shows photographs of the experimental unit with the glass and plastic covers.

Temperature Measurements

Temperatures of the constructed solar collector was measured by using 6 K-type thermocouples, one thermocouple was fixed in the Paraffin wax layer and two thermocouples were placed in the coal layer while the rest three thermocouples measured temperatures of the air gap. All thermocouples were connected to a control board. The control board had many circuit breakers connected to a digital reader. Every thermocouple was connected to a circuit

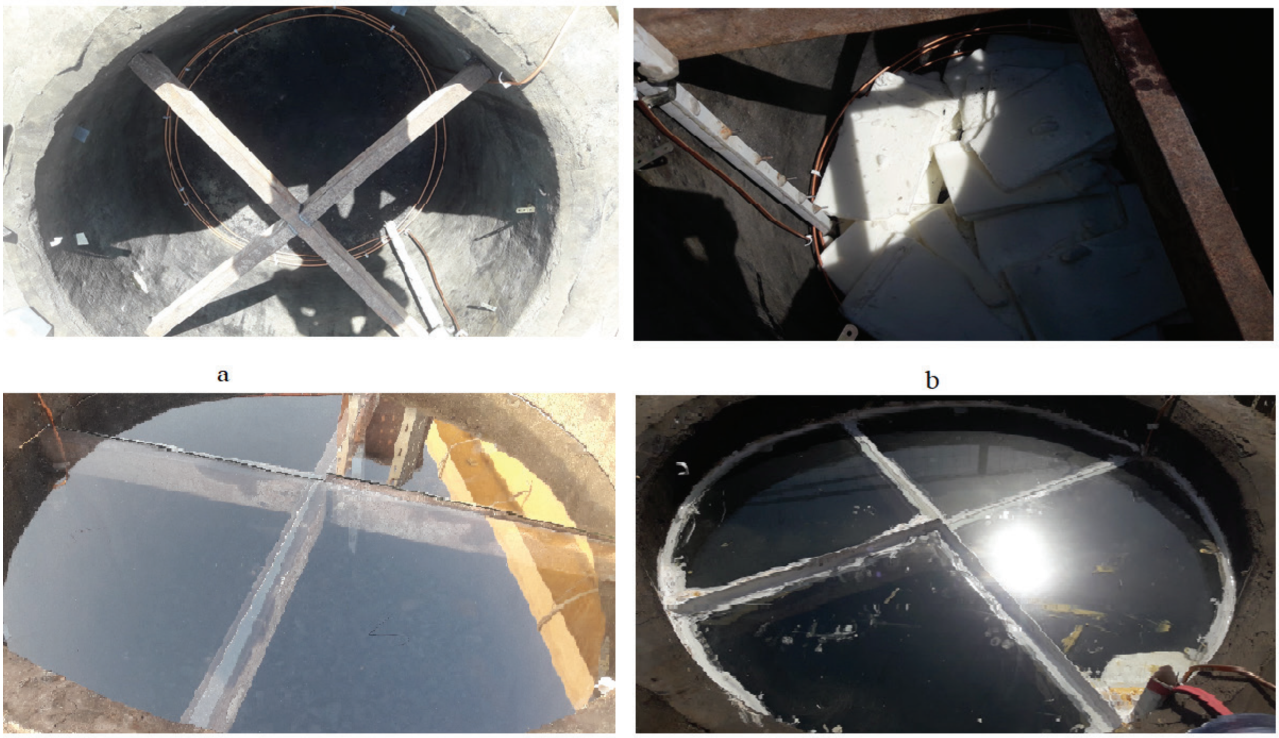

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Figure 1. Photographs of the experimental unit; (a) the copper coil at the bottom of the empty unit to be in the Paraffin wax layer for the heat extraction purposes; (b) the experimental unit when paraffin wax was added to represent a layer with a thickness of 10 cm; (c) the experimental unit after the addition of coal layer and adding the glass cover; (d) the experimental unit after completing the whole procedure. The experimental unit was constructed at the city of Nasiriya-south of Iraq and had three layers, a layer of paraffin wax with a thickness of 10 cm, a layer of coal with a thickness of 30 cm and a gap of air with 80 cm depth.

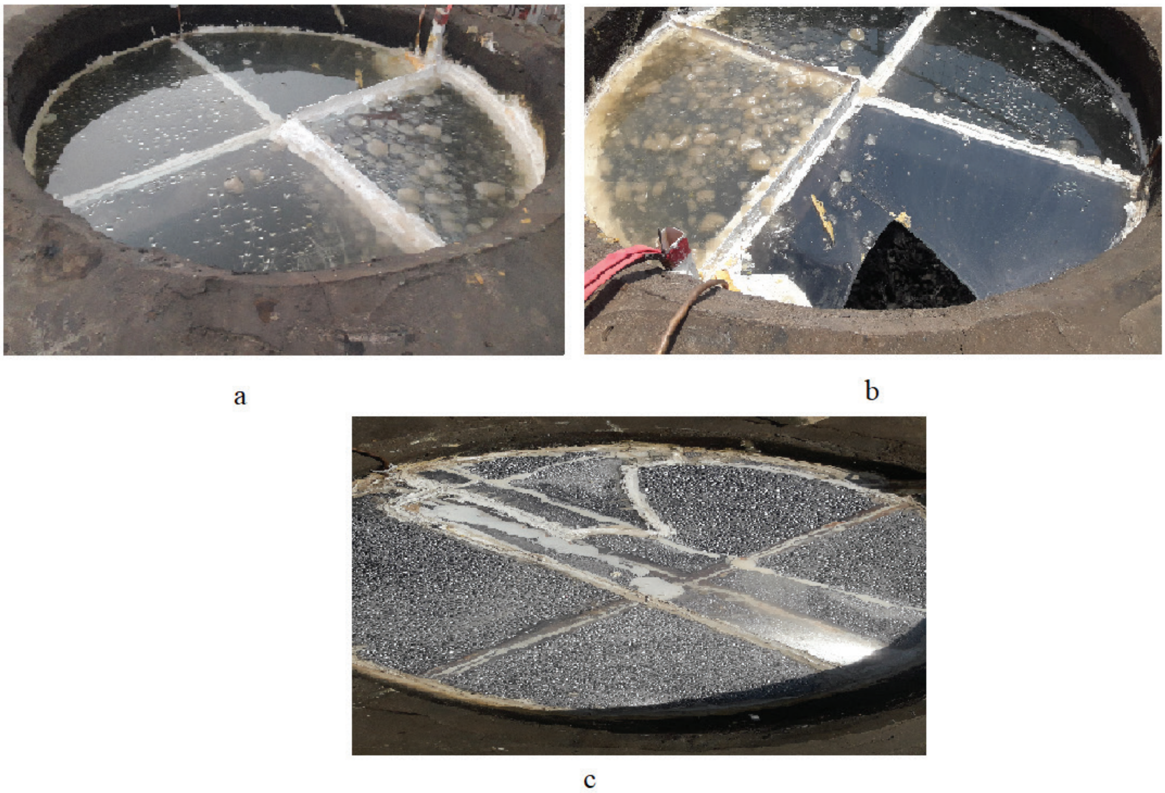

Figure 2. Photographs of the experimental unit; (a) the unit after the addition of 5 cm thick CMC gel layer; (b) the unit when the glass cover was broken; (c) the unit with the plastic cover showing drops of water condensed on the internal surface of the cover. The experimental unit was constructed at the city of Nasiriya-south of Iraq and had three layers, a layer of paraffin wax with a thickness of 10 cm, a layer of coal with a thickness of 30 cm and a gap of air with 80 cm depth.

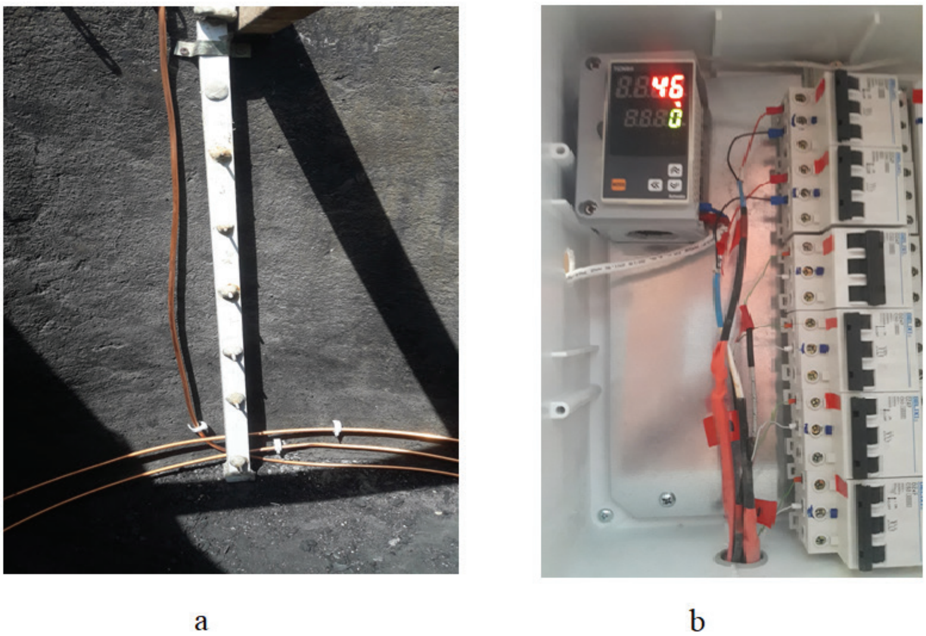

Figure 3. Temperature measurements; (a) the distribution of the thermocouples inside the experimental unit; (b) the used digital reader and circuit breakers fixed in the control panel. The experimental unit was constructed at the city of Nasiriya-south of Iraq and had three layers, a layer of paraffin wax with a thickness of 10 cm, a layer of coal with a thickness of 30 cm and a gap of air with 80 cm depth.

Table 1. Materials and tools used in the experimental work

1	Paraffin Wax
2	Coal
3	Glass cover
4	PVC cover
5	K-type thermocouples
6	Digital reader
7	Carboxylmethyl cellulose (CMC)

breaker and as mentioned this breaker was connected to the digital reader. Figure 3 illustrates the temperature measurements apparatus.

The used materials and tools to perform the experimental work are summarized in Table 1.

RESULTS AND DISCUSSION

This study investigated experimentally the performance of a novel solar collector when it was entirely different from the conventional solar collectors such as solar ponds. It was commenced in July 01/07/2021 by preparing the unit with the novel configuration, and then temperature measurements were started in July 17/7/2021. Temperature measurements of days 17 and 18 of July for the ambient, paraffin, the average of air gap and the average of coal temperatures are shown in Figure 4.

Figure 4 illustrates that the temperature of paraffin wax increases from 43 °C at the beginning (8 am 17/7/2021) to be 48 °C as the maximum (day time) then it decreases to be 46 °C as the minimum (night time) at the end (8 am 19/7/2021). As shown in Figure 4, the behaviour of temperature of paraffin wax is with a small discrepancy between day and night about 2 °C. Even two days is a short period, but the measurements of paraffin wax temperatures were encouraging since as shown in Figure 4, there is a small discrepancy between day and night temperatures (2 °C) with approximately high temperature (48 °C) comparing to the conventional SGSP collector with a discrepancy of 5-6 °C as concluded by Sayer et al., 2017 [21]. Simultaneously, the figure shows that there is a clear discrepancy in the ambient temperature between day and night (about 12 °C) while it is about 2 °C in the paraffin. Moreover, the temperature of the paraffin wax increased about 5 °C in only two days with a rate of increase of 2.5 °C/day. Sayer et al., 2017 [21] found that in the same area of the present study (Nasiriya City), the rate of increase in the temperature of the LCZ of a small open conventional SGSP was 2.25 °C/day when the temperature of the LCZ of their SGSP increased from 27 to 54 °C in 12 days. They also concluded that when the pond was covered with a thin liquid paraffin cover, the rate of temperature increase reduced to be 1.25 °C/day. The interpretation for this reduction in temperature was due to the accumulation of dust on the surface of paraffin layer and consequently attenuating the solar radiation penetration to the LCZ of the conventional SGSP. The pond had a surface

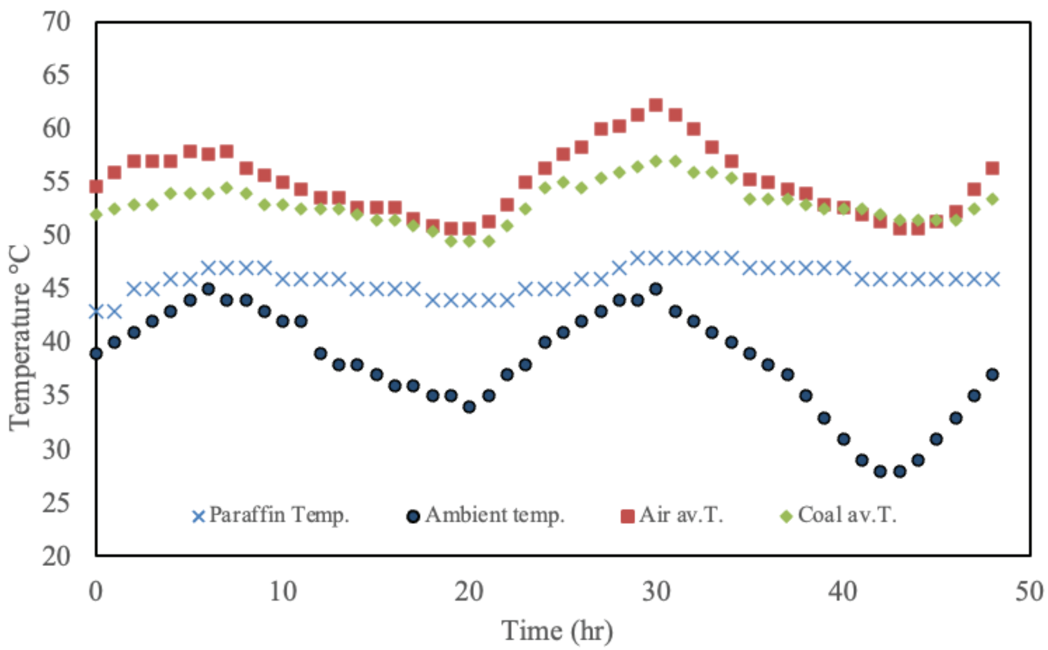

Figure 4. Temperature measurements of the experimental solar collector for two days (17-18/7/2021). The experimental unit was constructed at the city of Nasiriya-south of Iraq and had three layers, a layer of paraffin wax with a thickness of 10 cm, a layer of coal with a thickness of 30 cm and a gap of air with 80 cm depth.

area of 1 m^2 and the results were collected in approximately at the same conditions in summer season (from 29th of July-8th of August 2015) with similar ambient temperatures above forties. It is essential to emphasise that temperature of the storage zone (paraffin wax layer) of the present novel solar collector increased from 43- 48 °C while in the other conventional open pond (Sayer et al., 2017), it increased from 27 to 54 °C, and that means the driving force (temperature difference) of the conventional pond is higher than the driving force of the investigated solar collector in the present study. Consequently, it can be said if the new experimental unit started from 27 °C, the rate of increase in the temperature of paraffin wax layer would be noticeably higher than the recorded increase.

Furthermore, Figure 4 demonstrates that temperatures of the air gap and the coal layer behave identically to the ambient temperature. However, the differences between the coal layer, the air gap temperatures and the ambient temperature are about 14 and 17 °C respectively. This is another remarkable difference from the temperature behaviour of the conventional SGSP collectors when the temperature of the upper layer (UCZ) is mostly close to the ambient and sometimes lower than the ambient temperature in the night-time.

It is apparent that the novel solar collector can be a collector with three heat extraction layers or zones, the paraffin layer, the coal zone, and the air zone. Once again, this solar collector has many benefits. It is a system with no salt diffusion, no water and consequently no water addition to compensate the evaporated water. Moreover, there is no dust accumulation on the surface of the water, and no layer mixing which means the novel collector is a practical solar collector. Unfortunately, the glass cover of the pond was damaged in 19/7/2021 (Figure 2), and subsequently, the cover was replaced with a clear PVC cover. When the cover was broken the CMC gel layer (76 litres of water) went down to the pond and remained between the paraffin and coal layers.

Temperature measurements were resumed from 23-30/8/2021 with the PVC cover without the addition of CMC gel layer. The measurements are shown in Figure 5.

It is evident from Figure 5 that there is a variation in the temperature between day and night exclude the paraffin wax layer with a small discrepancy about 3-4 °C. The slight increase in this discrepancy (1-2 °C) could be explained by the presence of water which entered the collector when the glass cover was damaged as shown in Figure 2b. Figure 2c introduces an evidence of water effect on the collector. It shows that water evaporated and condensed on the internal surface of the plastic cover. This means that water formed a layer between the paraffin layer and the coal and extracts heat from the two layers to evaporate and consequently affecting their temperatures and simultaneously decreased the solar radiation penetrating to the bottom layers of the solar collector when it condenses on the internal surface of the plastic cover. To elucidate further, and for more clarification to the temperatures represented in Figure 5, Figure 6

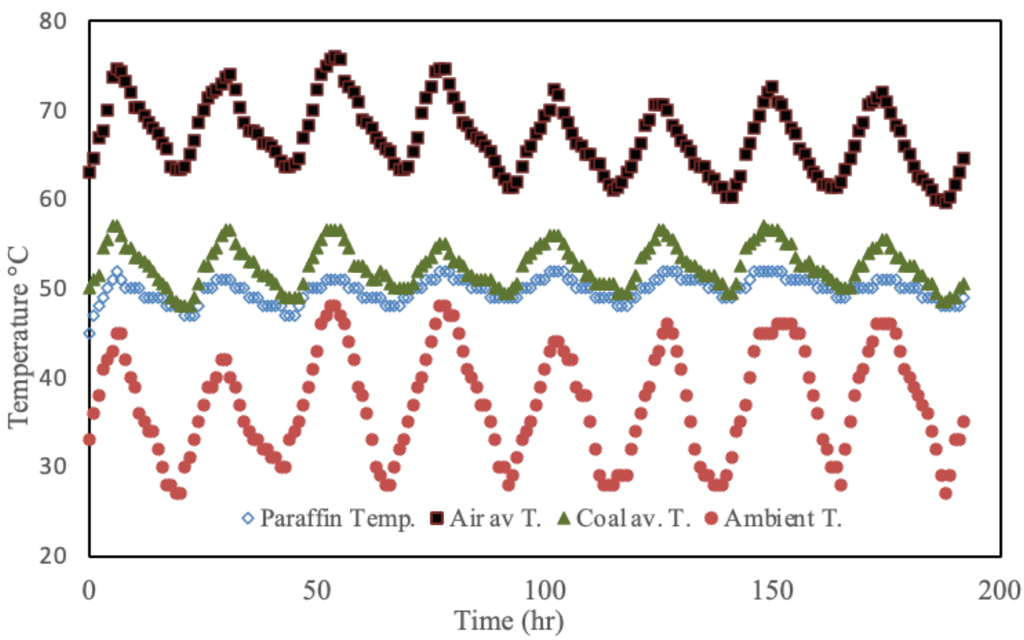

Figure 5. Temperature measurements of the experimental unit for the period 23-30/08/2021. The experimental unit was constructed at the city of Nasiriya-south of Iraq and had three layers, a layer of paraffin wax with a thickness of 10 cm, a layer of coal with a thickness of 30 cm and a gap of air with 80 cm depth.

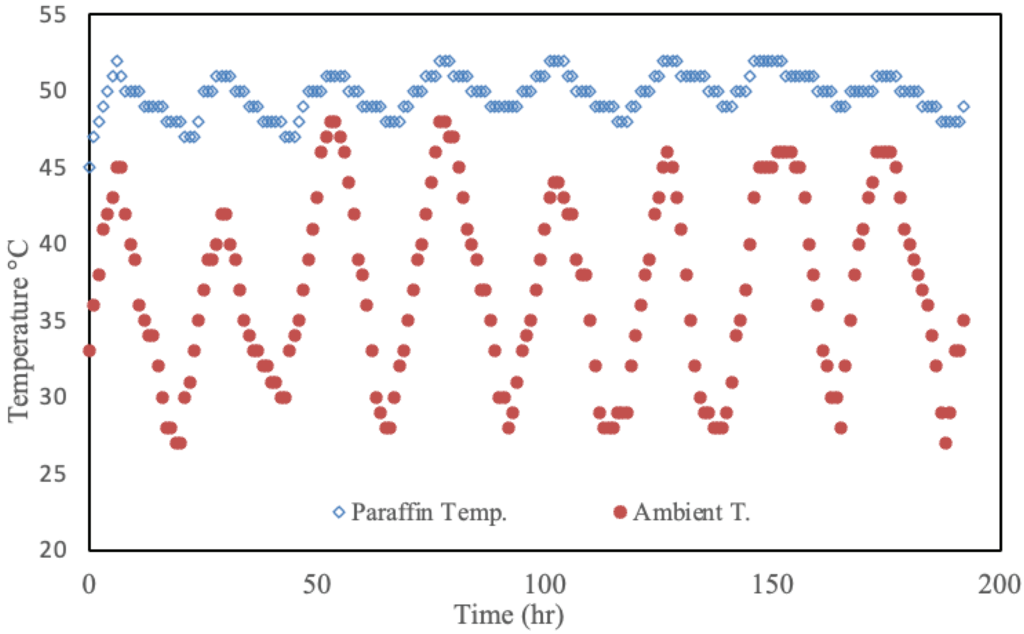

Figure 6. Temperature measurements of paraffin layer and the ambient temperature for the 8 days period. The experimental unit was constructed at the city of Nasiriya-south of Iraq and had three layers, a layer of paraffin wax with a thickness of 10 cm, a layer of coal with a thickness of 30 cm and a gap of air with 80 cm depth.

was split up for the measurements of paraffin wax layer and ambient temperatures.

It is apparent from Figure 6 that for the 8 days of measurements, there was a clear variation in the ambient temperature between day and night, the difference reached about 21 °C when temperature had the maximum of 48 °C in daytime and the minimum of 27 °C in night-time while it was no more than 4 °C for the paraffin wax layer. This could mean that paraffin layer absorbed the incident solar radiation and store the thermal heat with low heat loss in the night-time. During the 8 days of the measurements, temperature of the paraffin wax layer increased from about 45 °C to reach the maximum 51 °C with a rate of increase about 0.75 °C/day. This slight increase in the temperature occurred even there was a decrease in the incident solar radiation and this because after June there is a continuous decrease in the incident solar radiation towards winter season. Moreover, the presence of water in the bottom of the experimental unit when it was observed that water drops condensed on the internal surface of the plastic cover (Figure 2c) to represent a layer which made the collector opaque and significantly affected solar radiation penetration to the unit and consequently to the coal and paraffin wax layers. It can be observed that the variation in the temperature of the paraffin wax layer became higher than the case of the first two days at the beginning (17 -18 of July) when the glass cover was intact, and layers of the solar collector were dry.

From the discussion above, there is an indication that the new approach of the solar collector has three thermal storage zones, the paraffin layer, coal layer, and the air gap. Moreover, as it was previously mentioned in the experimental part that the glass cover was broken, and this meant about 76 litres of water moved into the unit. Although the unit was left open, water remains inside it. This was proved by the presence and accumulation of water drops on the bottom surface of the glass cover. Therefore, to tackle the problem, the experimental unit was opened on 1/9/2021 and plastic cover was removed. Interestingly, It was found that water formed a layer below the coal layer, and this affected the temperature increase inside the experimental unit. Water was removed, and wet coal layer was replaced by a dry coal layer. Then the constructed solar collector was left open for two weeks for complete dryness. A second copper coil was fixed in the gap layer; it had the same dimensions of the coil fixed in the paraffin wax layer. Figure 7 shows the experimental unit after the removal of water and the installation of the copper coil in the air gap for the heat extraction.

It is clear from Figure 7 that the second copper coil is fixed in the air gap in the area above the coal layer. After the dryness of the experimental unit, temperature measurements were recorded for the final two weeks of September (from 15th -30th of September). The results are shown in Figure 8.

It is evident from Figure 8 that there is a clear discrepancy in the temperatures between day and night for all

Figure 7. A Picture of the experimental unit after the removal of water and wet coal and the installation of the second heat exchanger (copper coil). The experimental unit was constructed at the city of Nasiriya-south of Iraq and had three layers, a layer of paraffin wax with a thickness of 10 cm, a layer of coal with a thickness of 30 cm and a gap of air with 80 cm depth.

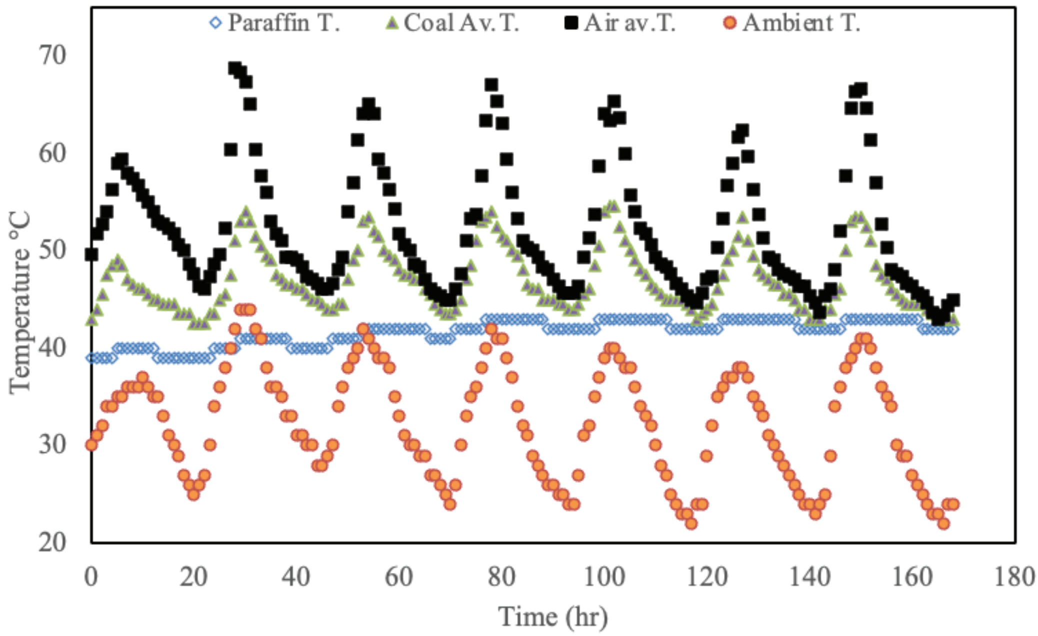

Figure 8. Temperature measurements of the experimental unit for the period 15-30/09/2021 after the unit dryness and replacing the coal. The experimental unit was constructed at the city of Nasiriya-south of Iraq and had three layers, a layer of paraffin wax with a thickness of 10 cm, a layer of coal with a thickness of 30 cm and a gap of air with 80 cm depth.

measured temperatures excluding the temperature of paraffin wax. In the selected period (15-30/09/2021), ambient temperature varied between about 42 °C in daytime to 22 °C in night-time with a difference about 20 °C. As shown in Figure 8, temperatures of air gap and coal behaved similarly to the ambient temperature with a discrepancy about 23 °C and 11 °C for the air gap and coal layers respectively. Their temperatures (air gap and coal) reached the maximum around 70 °C and 53 °C respectively. The recorded temperatures are encouraging and consequently heat can be extracted from the two zones during the daytime to be used in many applications. For the two zones (air gap and

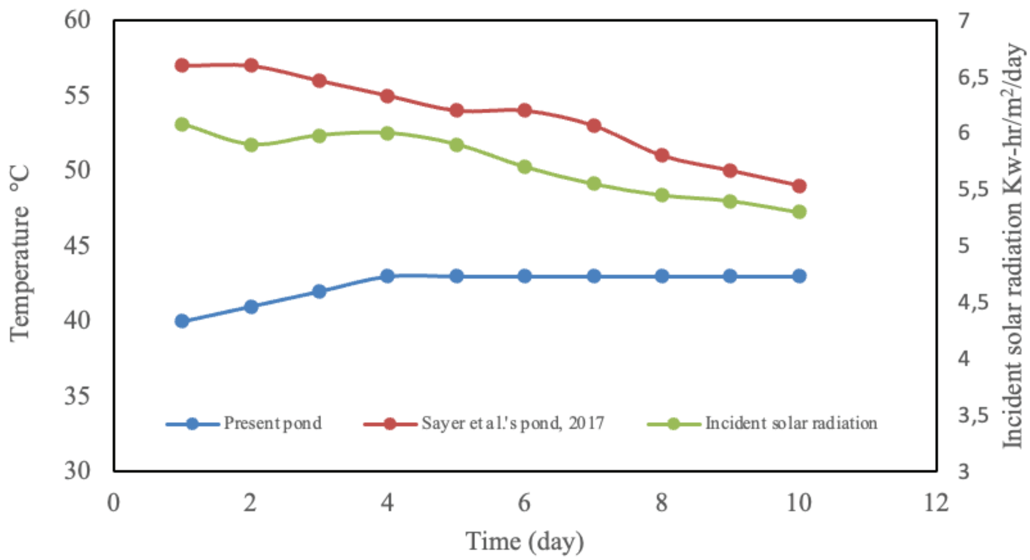

Figure 9. Temperature measurements of the experimental unit for the period 15-30/09/2021 after the dryness and replacing the coal and temperature measurements of Sayer et al., 2017's pond and radiation values in the same period. The experimental unit was constructed at the city of Nasiriya-south of Iraq and had three layers, a layer of paraffin wax with a thickness of 10 cm, a layer of coal with a thickness of 30 cm and a gap of air with 80 cm depth.

coal), despite the decrease in their temperatures at night, temperatures remained above 40 °C which is suitable for a wide range of industrial applications; this was even with low ambient temperature at night about 22 °C. Figure 8 shows clearly that the gaps between ambient temperature and air gap and coal temperatures are approximately constant through the whole day about 23 °C and 14 °C for the air gap and coal respectively.

Interestingly, as illustrated in Figure 8, for the the paraffin wax, there is a very small discrepancy in the temperature between the day and night (about 1 °C). For the whole period (15-30/09/2021), the temperature increased from about 39 °C at the beginning of the experimental work to reach 43 °C and remained approximately constant around this degree. It is significant to emphasise here that even with the continuous decrease in the incident solar radiation and ambient temperature throughout this short period, there is no significant decrease in the temperature of the paraffin wax layer. To clarify this point further, the results of the present study for this period (15-30/09/2021) were compared with the temperature measurements of the storage zone (LCZ) of the experimental pond of Sayer et al., 2017[21] for the same period. The experimental measurements of both solar collectors and the daily incident radiation taken from NASA [26] are plotted against the time progress in days and illustrated in Figure 9.

Figure 9 shows that the temperature of the novel unit of the present study behaves entirely in a different way from the covered conventional salinity gradient solar pond of Sayer et al., 2017 [21]. The temperature evolution of the conventional pond follows the evolution of the incident solar radiation. As shown in the figure, there is a continuous decrease in the insolation, and this followed by continuous decrease in the temperature of the storage zone (LCZ) of Sayer et al.'s pond[21]. On the other hand, the temperature of paraffin wax layer remained approximately constant when insolation is in a noticeable continuous decrease.

The new findings of the present study invite more research in the new approach of solar collectors. There is a need for more studies to investigate the optimisation of the thickness of paraffin wax and coal layers. In addition to more investigations on the optimal depth of air layer and thickness of the surface cover of the collector.

CONCLUSION

The performance of the conventional solar collectors including SGSPs is significantly affected by many challenges. These challenges can include the temperature discrepancy between day and night, evaporation from the surface and the upward salt diffusion. The removal or limitation of these challenges would profoundly contribute to the expansion of this solar application.

- The present study introduces a novel attempt to change the direction of solar collectors entirely by investigating a solar collector with no liquid or no water body.
- To achieve the purpose of the study, an experimental solar collector was constructed in Nasiriya City, south of Iraq with a total depth of 1.4 m. The novel unit had three layers, a paraffin wax layer with a thickness of 0.1

m covered with a coal layer with a thickness of 0.3 m, and finally an air gap was left on the top of the coal layer.

- The results clearly showed that in the novel configuration, the temperature of the paraffin wax behaved differently from the storage zone of the conventional SGSP. The temperature in this layer (paraffin wax) reach more than 48 °C and then remained constant around 43 °C with a small day and night discrepancy.
- Further research is essential to cover the new parameters in the novel configuration of solar collector.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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